MIT International Center for Air Transportation

MODELING CONFORMANCE MONITORING APPROACHES IN ATC ENVIRONMENTS

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CONFORMANCE MONITORING

- **Conformance monitoring function is a core task in ATC operations to verify that aircraft adhere to conflict-free, efficient trajectories**
  - Flight Plan
  - Standard flows
  - ATC vectors
- **Ability to perform conformance monitoring depends on surveillance/communication environment**
  - Surveillance level sets observability of aircraft behavior
  - Communication level sets ability to pass intent information
- **Added interest in conformance monitoring in light of events of September 11, 2001**
  - Detection of ‘rogue’ aircraft deviating from cleared or nominal procedure trajectories

RESEARCH GOALS

- **Investigate conformance monitoring approaches in current and future ATC environments**
  - Assess importance of surveillance & communication of varying levels and qualities of dynamic state and intent information on conformance monitoring functions
    - Detection of non-conformance
    - Intent inferencing
- **Guide datalink message requirements**
  - Contents
  - Bandwidths
  - Update rates, etc.
- **Assess ability for new operating paradigms with introduction of advanced conformance monitoring systems**

CONFORMANCE MONITORING PROCESSES

REAL WORLD

Manual control

FMS CDU

AUTO-PILOT

Observed state behavior

Communication

Surveillance

"CONFORMANCE BASIS"
E.g. Flight Plan, Standard flow, ATC vector

CONFORMANCE MONITORING
Is observed behavior consistent with expected behavior?

PILOT INTENT MODEL

AIRCRAFT INTENT MODEL

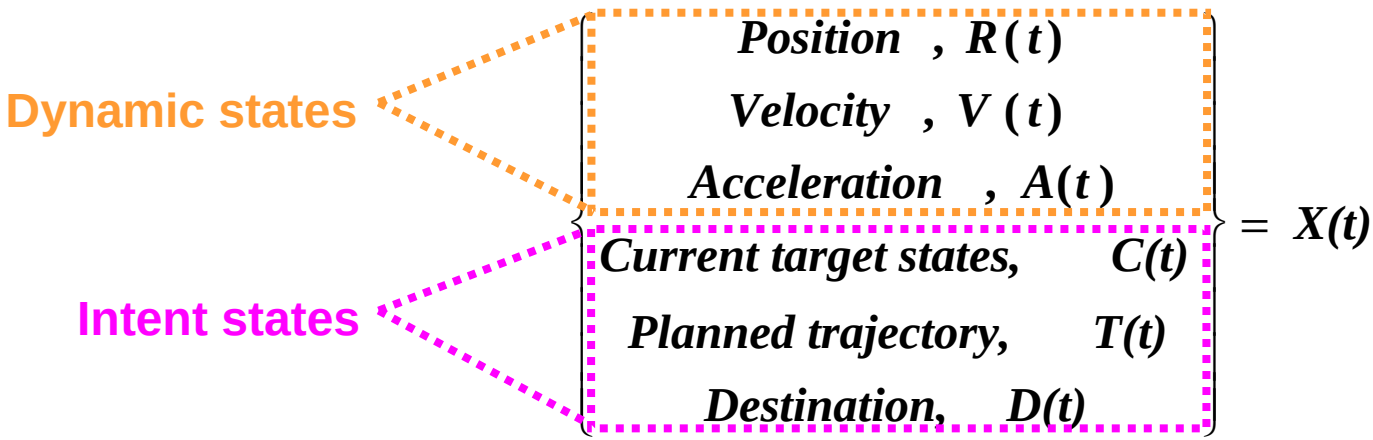
A/C CONTROL SYSTEM & DYNAMICS MODEL

MODEL OF REAL WORLD

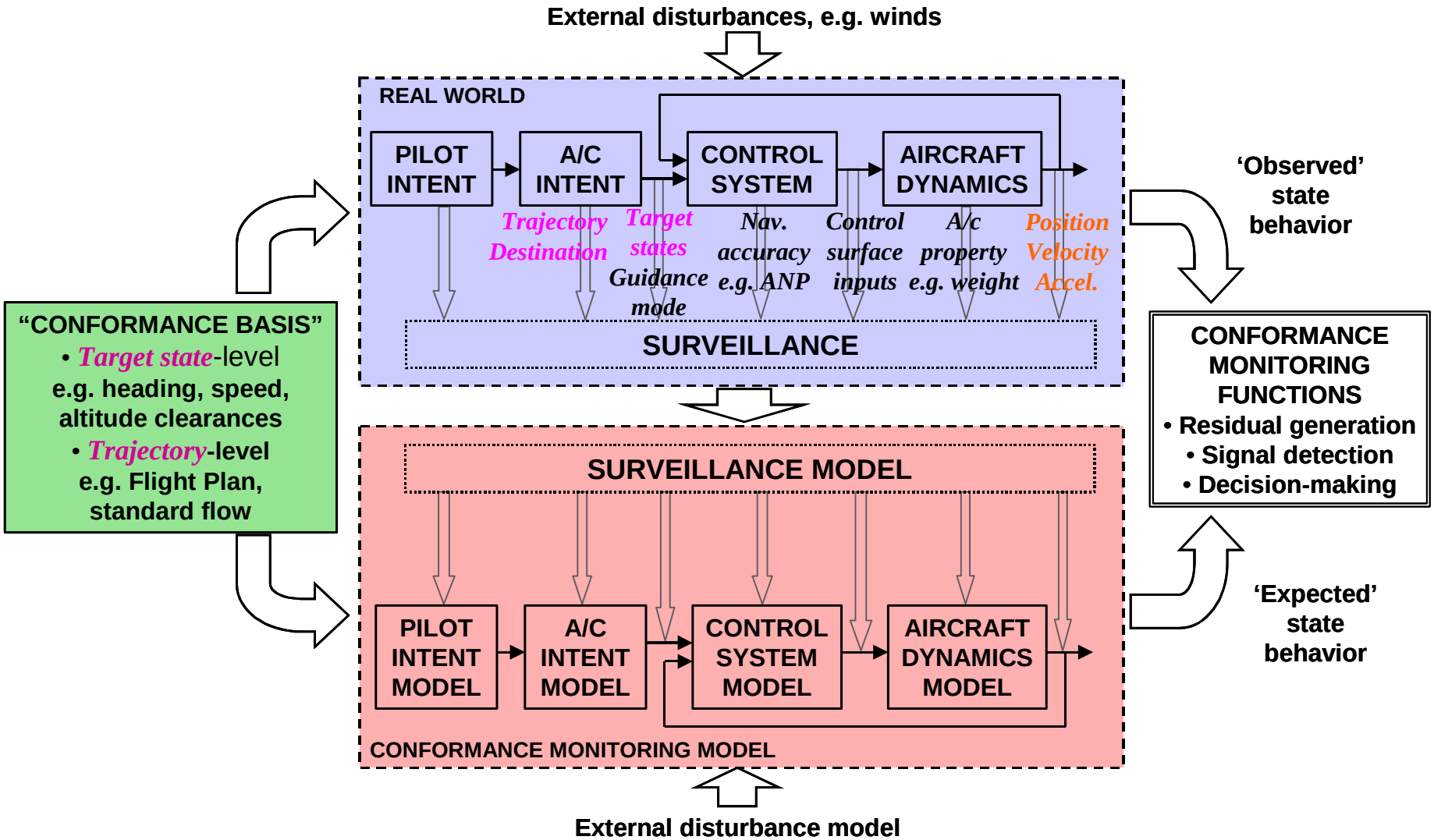
Expected state behavior

SURVEILLANCE STATE VECTOR

- **No formal relationship between surveillance/communication level and understanding of current & future aircraft behavior**
- **"Surveillance state vector" approach formalizes relationship between dynamic and intent states in a way consistent with:**
  - Autopilot driving to a target state
  - The way the FMS uses a linked series of target states to generate a trajectory to control the route to the desired destination



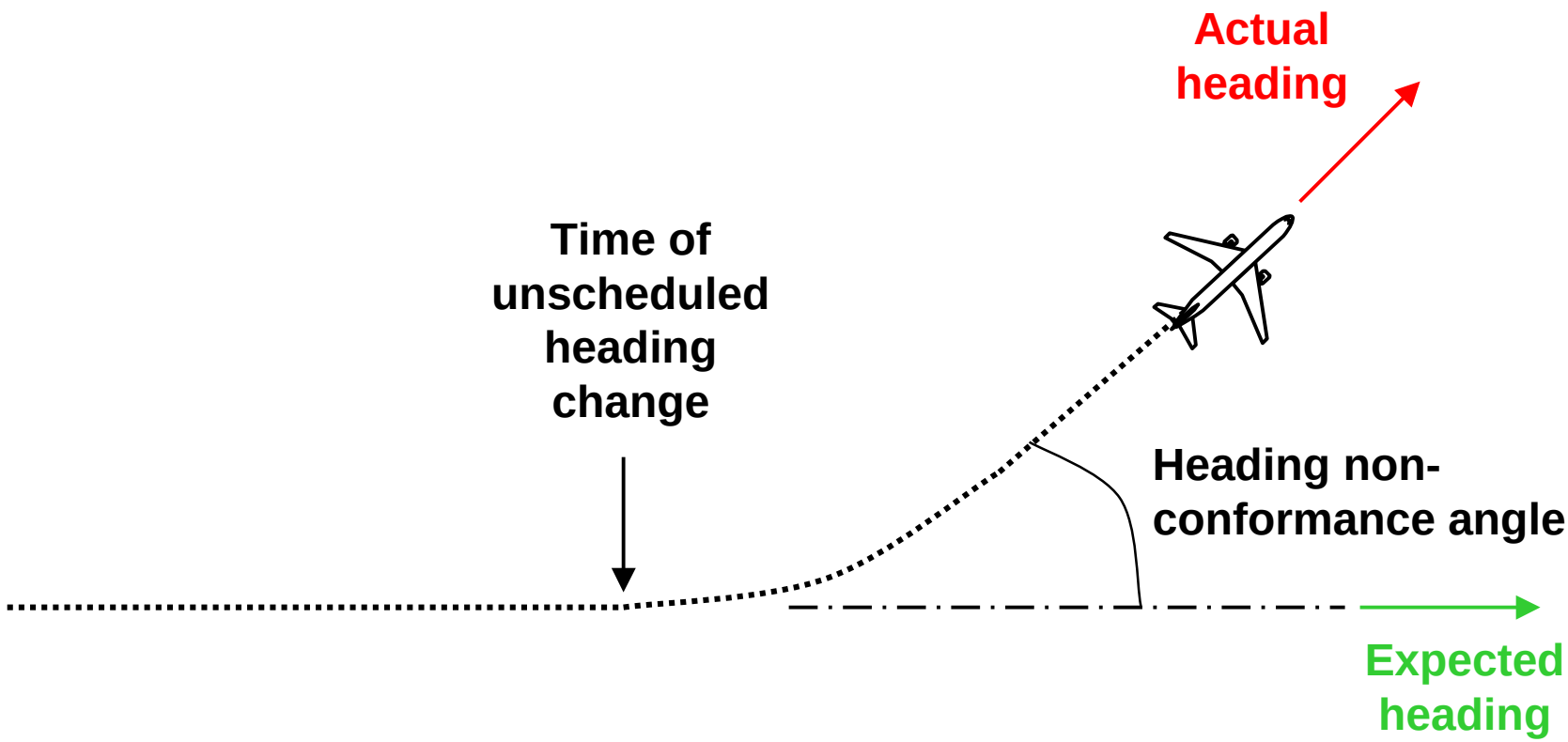
CONFORMANCE MONITORING ANALYSIS FRAMEWORK



CONFORMANCE MONITORING MODEL & FUNCTIONS

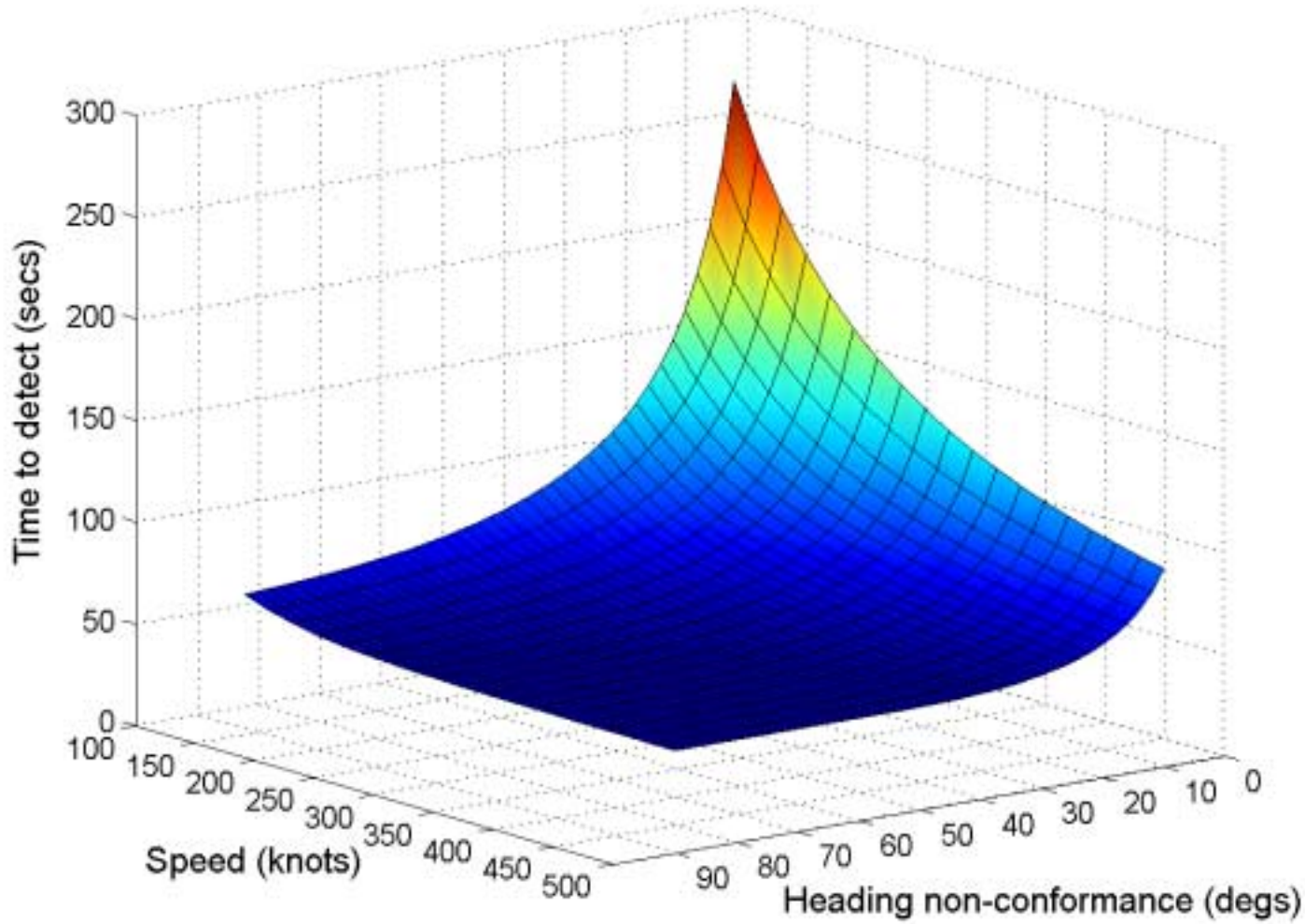
- **Test framework in simulation trials**
- **Conformance monitoring model block executed in Simulink**
- **Simulink models being developed of:**
  - Lateral control system & dynamics
  - Surveillance systems
- **Generic point mass model with large commercial a/c properties**
  - Roll-in/roll-out dynamics
  - Actual Navigation Performance (ANP) characteristics
    - 95% cross-track containment limit, e.g. ANP-1.0 = 1.0 nm cross-track containment for 95% of flight time
- **Models integrated with MATLAB code to perform conformance functions**
  - Residual generation
  - Signal detection
  - Decision-making

EXAMPLE RESULTS SCENARIO



EXAMPLE RESULTS

Time to detect non-conformance as functions of speed & heading non-conformance angle

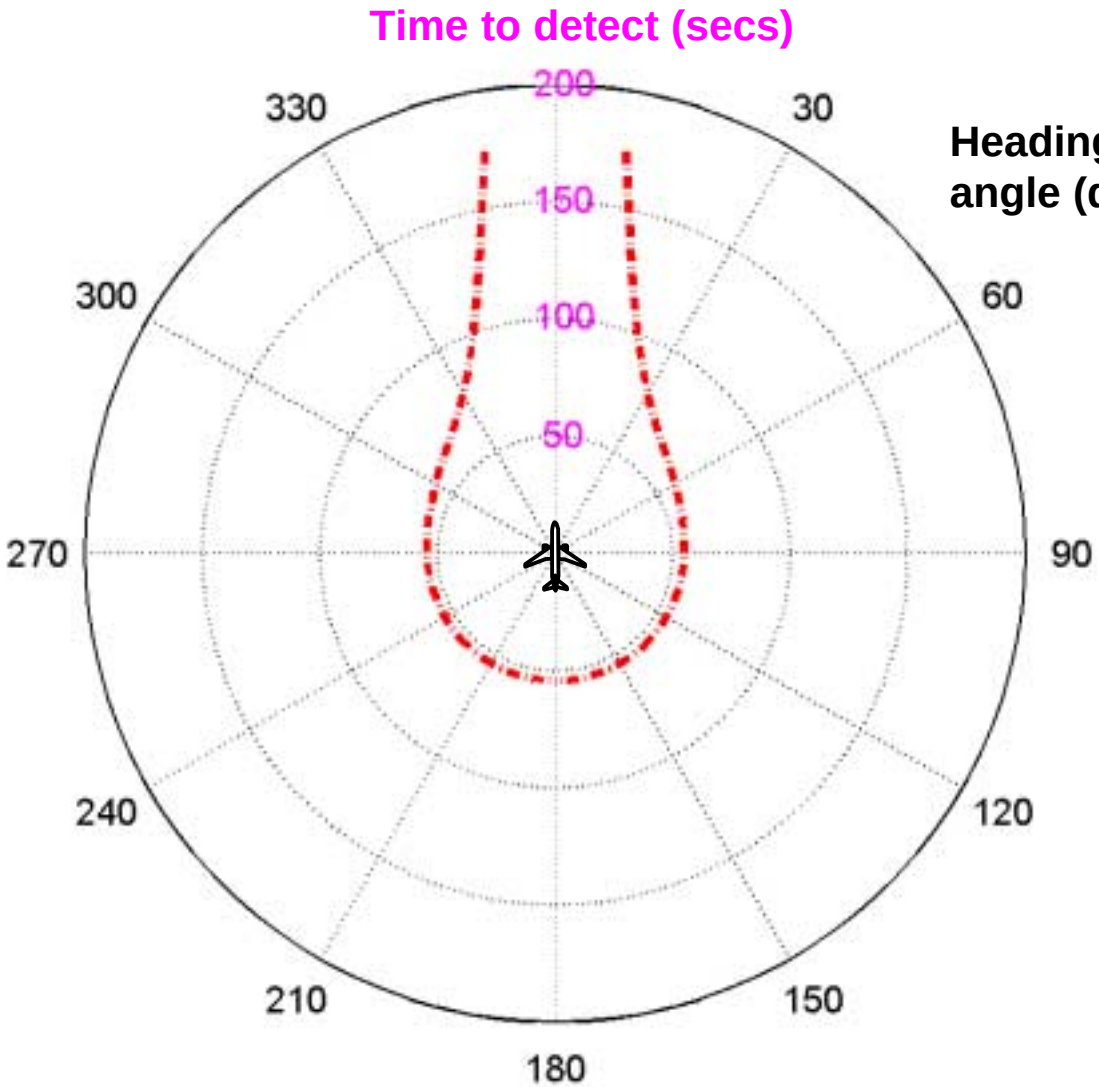


Zero tracking error & time uncertainty

Position surveillance noise = 2500 ft (1 sd), P(false alarm) = P(missed detection) = 2.5%

EXAMPLE RESULTS

Time to detect non-conformance at given speed



Heading non-conformance angle (degs)

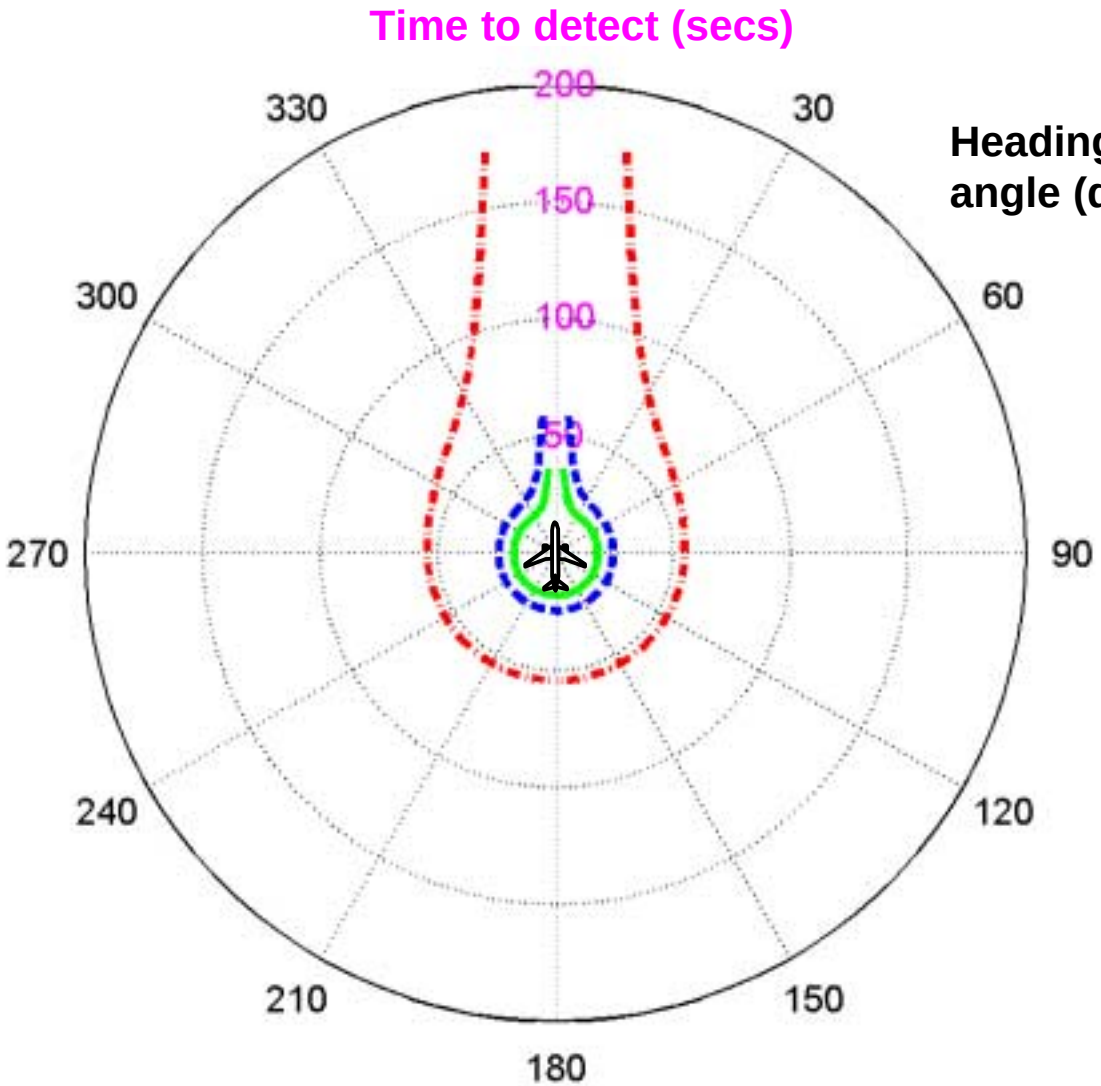
Position surveillance noise (1 sd):

2500ft

Speed = 250 knots, P(false alarm) = P(missed detection) = 2.5%

EXAMPLE RESULTS

Time to detect non-conformance at a given speed as a function of surveillance quality



Heading non-conformance angle (degs)

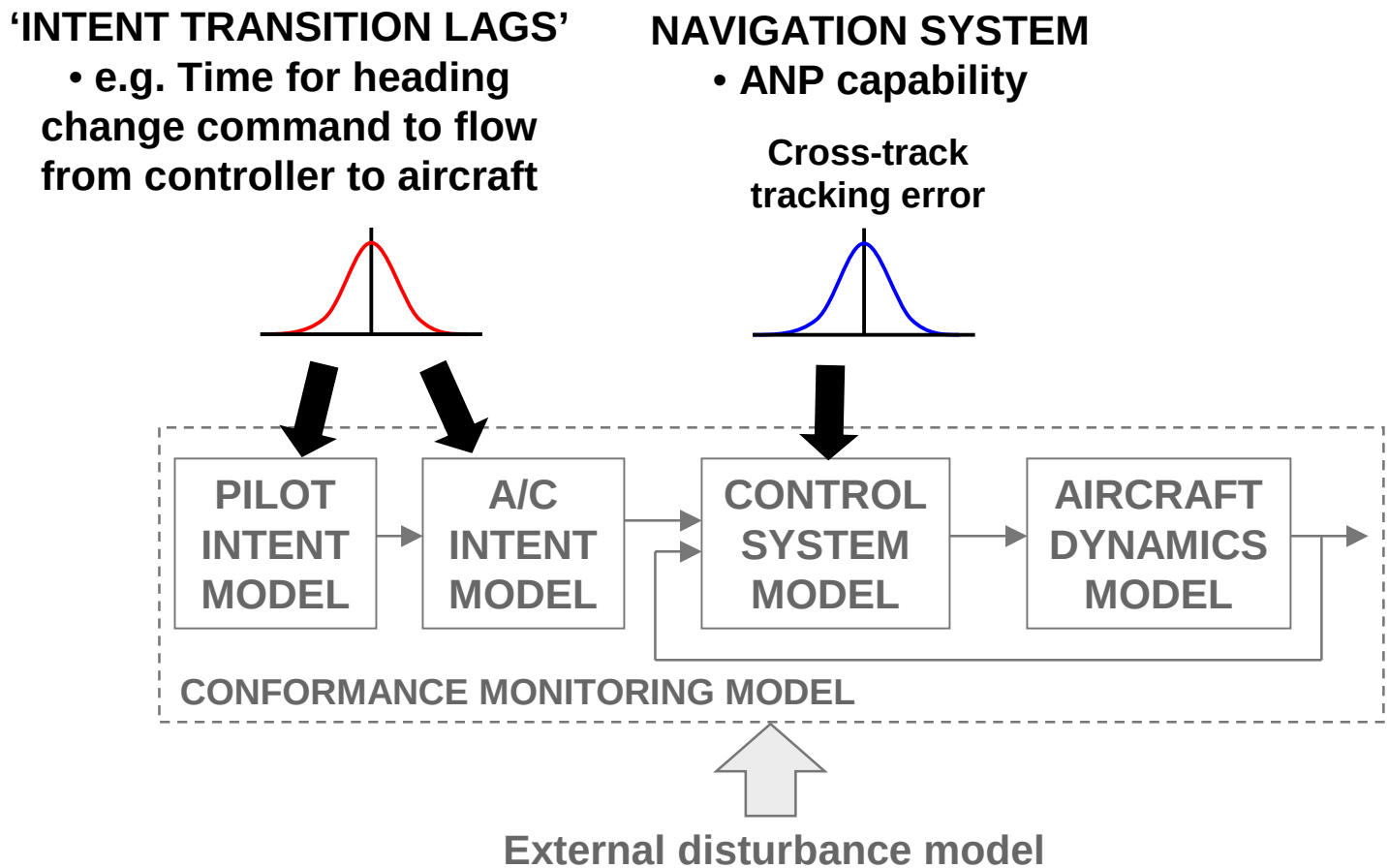
Position surveillance noise (1 sd):

- 2500ft
- 600ft
- 250 ft

Speed = 250 knots, P(false alarm) = P(missed detection) = 2.5%

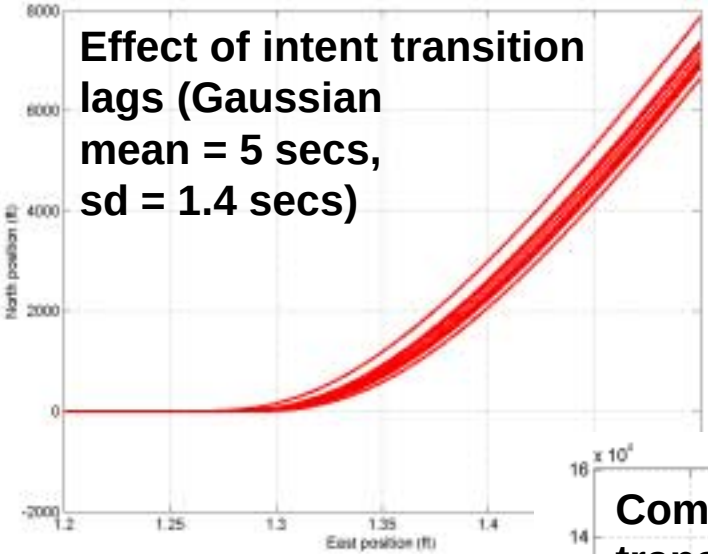
EXAMPLE MONTE CARLO INVESTIGATION ISSUES

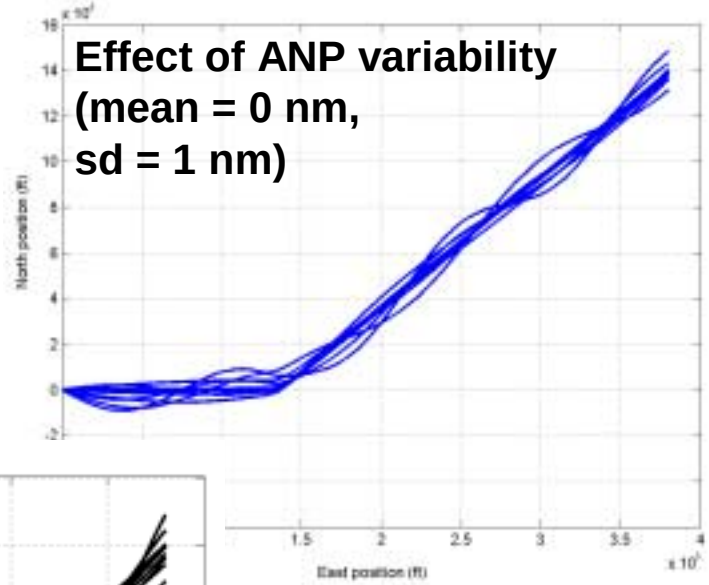
- **Calibration of framework method**

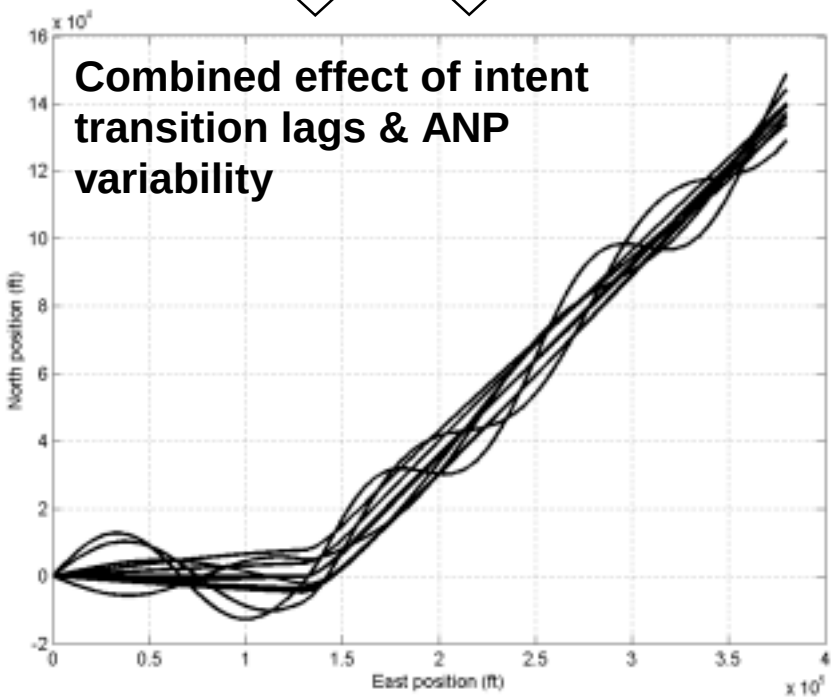


EXAMPLE RESULTS

Monte Carlo investigation of intent transition lags & ANP variability effects







- 30deg heading change command issued at time t = 300 secs
- Speed = 250 knots
- 10 runs shown

CONCLUSIONS & FUTURE WORK

- **Proposed conformance monitoring framework and simulation approach enables us to investigate conformance monitoring approaches under different surveillance and operational envts.**

Next steps:

- **Refine lateral models**
  - ☐ Trajectory-following guidance
  - ☐ Higher fidelity navigation system tracking and aircraft dynamic effects
  - ☐ Wind effects
- **Investigate modeling vertical modes**
- **Defining and analyzing scenarios of interest**
- **Human in the loop studies**
  - ☐ Commercial flight simulator representing “Real World” component
  - ☐ Simulink/MATLAB representing “Conformance Monitoring Model” and “Conformance Function” components